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# 161. Exposure to chemicals in food packaging as a sustainability trade-off in LCA

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**ABSTRACT**

Hazardous chemicals in packaging, including 'eco-friendly' and recycled food packaging, can migrate into food and expose humans. LCA has been fundamental to indicate more 'eco-friendly' packages, but currently LCA does not consider exposure to chemical migrants and methods have not yet been developed. In this study we question if exposure to chemicals in food packaging should be considered as a sustainable design consideration, i.e. if this human health risk is relevant in a life cycle context. To answer this question, we focus on developing methods to quantify exposure to chemicals in food packaging in a life cycle impact assessment (LCIA) framework. To put exposure during use in a life cycle context we perform a screening-level LCA of several life cycle stages of high impact polystyrene packaging (HIPS), with a functional unit of containing and delivering one kilogram of yogurt for consumption. For screening, we include exposure via environmental emissions from the production of the raw material HIPS, thermoforming into packaging, 14 day refrigeration by consumers, and disposal via incineration. The purpose of this screening is not to obtain a detailed and accurate LCA of HIPS but to provide life cycle context to compare the magnitude of characterized exposure to chemicals in packaging, in order to elucidate if this exposure pathway is important. We detail estimates of life cycle exposure to one known hazardous chemical in polystyrene packaging (styrene) that has data available on concentrations in yogurt packaged in HIPS and life cycle inventory releases. We also extend this analysis, given data limitations, to include exposure to three other chemicals in HIPS packaging through food. Given that data on concentrations of food packaging chemicals in food are often missing, we also explore methods to model the product intake fraction (PiF) as the fraction of chemical mass taken in through food packaging versus its initial mass in the food packaging. Results demonstrated that in the given cases consumer exposure to chemicals in packaging through consuming packaged food can be greater than population-level exposure mediated by the life cycle releases of such chemicals, even when only considering one or several chemicals in packaging that expose consumers. Occupational exposure was not considered in this study, but could be a focus of future work. Thus, this initial exploration indicates that exposure to chemicals in food packaging can be an essential consideration for burden shifting and quantifying design trade-offs in a life cycle context.

Keywords: life cycle impact assessment, food contact materials, high impact polystyrene, human health, product intake fraction

## 1. Introduction

Food packaging claiming to be more environmentally sustainable has the potential to increase human exposure to toxic chemicals through packaged food. For example, recent tests that compared with conventional food packaging have detected higher levels of toxic fluorinated chemicals (Blum et al. 2015) in 'eco-friendly' food packaging (Yuan et al. 2015) and phthalates (Serrano et al. 2014) in recycled food packaging (Gärtner et al. 2009). Very few assessment frameworks evaluating 'sustainable' product design, for instance for packaging, consider human exposure to chemicals when *using* a product alongside a product's environmental impacts. To date, established methodologies are restricted to hazard identification. For example, products that are Ecolabel licensed (www.ecolabel.eu) or Cradle to Cradle Certified$^{CM}$ (C2C) must verify they do not contain a list of hazardous chemicals of concern, e.g. according to the C2C Material Health Criteria, in order to increase safety beyond current

regulatory requirements. Using a qualitative hazard-identification based method offers several advantages, namely quantification of exposure is not needed. However, such an approach does not offer the possibility for exposure minimization strategies for the thousands of chemicals that are (or are not) on an assessment's self-made 'banned' list, but legally allowable in food contact materials. Furthermore, such a hazard-based approach does not allow for considering exposure to chemicals in packaging as a system or design impact trade-off.

Life cycle assessment (LCA) has been extensively applied to food and beverage packaging systems (Flanigan et al. 2013; Grönman et al. 2013) and results have for example supported transitioning from glass to plastic food contact materials to decrease environmental impacts (Hunt and Franklin 1996). Specifically, LCAs on packaging for baby food, injectable medicines, and beverages have indicated plastic having less potential for human toxicity and climate change *mediated by environmental emissions* mostly due to the lower weight and melting temperature of a unit of plastic versus glass (Humbert et al. 2009; Belboom et al. 2011; Amienyo et al. 2012; Gérand and Roux 2014; Dhaliwal et al. 2014). LCA of plastic waste also generally supports recycling to reduce environmental impacts and resource consumptions (Laurent et al. 2014). Human exposure research, however, indicates that plastic and recycled food packaging can be a substantial contributor to dietary intake of potential toxic chemicals (Geueke et al. 2014; Lee et al. 2014). LCA-compatible quantitative methods that consider human exposure and toxicity characterization of chemicals in food contact materials are not yet developed to inform 'sustainable' product design that considers human exposure through product use.

A criticism of including exposure to chemicals in food packaging within sustainability assessments is that such exposures should be 'safe' according to regulatory compliance, and therefore no further consideration is needed. Compliance with regulatory thresholds, however, does not offer means of identifying areas of **exposure minimization**, and furthermore does not offer consideration of **exposure in a life cycle context** e.g. where package A and package B can both comply with regulations, however one package may lead to lesser exposure than the other via environmental emissions throughout its life cycle or through use. In addition, guidance on applying regulatory safety standards are lacking for most food contact materials, such as food packaging, like paper and board where no EU-wide migration exist and therefore it is unclear if and how chemical safety of these materials is ensured, especially when it comes to use of recycled materials. A recent analysis of chemicals listed for food contact materials shows that there are at least 175 chemicals of concern legally used in food contact materials, with evidence of migration into food for some of these substances (Geueke et al. 2014; Geueke and Muncke, submitted).

In this study we explore science-based methods to inform decision making about packaging design that considers exposure to chemicals in food from packaging as a possible sustainability trade-off. Trade-offs can occur when decreased life cycle impacts based on other environmental indicators (e.g. decrease greenhouse gas emissions via transport by replacing glass with lighter weight plastic) incidentally increase potential for exposure through package use. On the other-hand trade-offs can also occur if efforts are made to decrease exposure (e.g. use of only virgin material) that can lead to increased life cycle impacts. For the first time, we present LCA-compatible methods for assessing exposure to chemicals in food packaging and we test if such exposure **is important in a life cycle context**.

## 2. Methods

We developed methods to analyze the relevancy of exposure to chemicals in food packaging in a life cycle context in terms of exposure magnitude and to eventually quantify exposure as a potential design trade-off. We selected high impact polystyrene (HIPS) as a packaging material to focus the analysis for data procurement. A reference flow of 8 HIPS cups of 125mL each, resulting in 0.017 of

HIPS materials used (Robertson 2012), to provide the function of containing and delivering 1kg of yogurt to consumers. Yogurt was chosen as the packaged food item because concentrations of chemicals migrating from HIPS were available through a recent food screening study by the United States Food and Drug Administration (US FDA) (Genualdi et al. 2014), and packaging dimensions were available (Robertson 2012).

**To put exposure via package use (i.e. consuming packaged food) in a life cycle context, first, we characterized human toxicity potentials of the emissions resulting from various HIPS life cycle stages**: HIPS material acquisition, thermoforming of HIPS into packaging, 14 day (in-home) refrigeration of the packaged food, and incineration. The life cycle inventory (LCI) from these stages were selected from ecoinvent v3.1 (Weidema et al. 2013) with default system allocation. Human exposure to life cycle emissions via environmental fate was estimated according to the ILCD methodology which relies on USEtox, where the impact (*I, cases*) is estimated as a function of the mass emitted ($m_e$, *kg*), the population-scale human intake fraction (*iF kg taken in per kg emitted*), and the EF (*cases per kg taken in*), $I = m_e \times iF \times EF$. The purpose of this exercise was not to perform a full LCA of HIPS food packaging, but to obtain basic screening to allow comparison to life cycle impacts according to default database values for unit processes. We are then able to identify potential human toxicity to compare for the first time exposure through consuming packaged food in a life cycle context.

The chemical inventory from life cycle stages were matched to chemicals known to occur in HIPS according to the US FDA (Genualdi et al. 2014) and the European Commission (Hoekstra et al. 2015) to identify chemicals where exposure could be tracked throughout the life cycle stages, including exposure via packaged food. Thereby, given the occurrence of a substance in HIPS and quantifiable mass transfer into food (exposing consumers), as well as occurrence as an HIPS life cycle emission and quantifiable fate and population-level exposure through the environment, we were able to explore in detail exposure magnitudes for a given chemical across the packaging life cycle. We also characterized this exposure using comparative toxicological units for humans (CTU) measured in potential disease cases, according to effect factors in USEtox, using a 1:1 route-to-route effect extrapolation for oral and inhalation exposure as suggested by Rosenbaum et al. (2011).

**The novel contribution of this study is to provide a first demonstration and test of including exposure to chemicals in food packaging in a life cycle context. Thus, following the life cycle screening we characterize the mass of chemical within a package that migrates from the packaging into the food item thus exposing humans.** Given weight per weight concentration (*C, mg/kg*) of a chemical in food, a mass of food ($m_f$, *kg*), the assumption that 100% of the food item is ingested, and effect factors (*EFs, disease cases* $kg^{-1}$) we estimated impact (*I, disease cases*) as $I = C \times m_f \times EF$. Specifically, for styrene we relied on empirical data on the concentrations in yogurt packaged in HIPS (Genualdi et al. 2014). When chemical concentrations were not known, we used the allowable amount migrating into food from packaging, according to EU authorities, and also quantified the resulting impacts for various percentages of this amount. When EFs were unavailable from USEtox, EFs were extrapolated from available No Observed Adverse Effect Levels (NOAELs) from animal experiments according to the methods used to derive the EFs in USEtox (Huijbregts et al. 2005). Thus we were able to include exposure to chemicals in packaging in an LCA context, and also compare to LCIA results for other life cycle stages. Finally, we screen all life cycle potential human toxicity impacts when including exposure through packaged food consumption for 'hot spots' to determine if exposure to chemicals in food packaging via use could potentially be a hot spot in LCAs of food packaging. Hot spots were identified as the largest contributors to HTP in the assessed life cycle processes (stages).

Chemical occurrence in packaging, transfer into food, and EFs are necessary components of our developed LCIA methodology to characterize chemicals in packaging. However, even when a

practitioner knows the chemical concentration occurring in a package, they may not know the mass transfer into various food items leading to exposure. Thereby to address such a data gap, we explore modeling exposure by various chemical-package-food combinations and aim to operationalize modeling approaches for LCIA. Chemical transfer from packaging into food was modeled as the product intake fraction metric (Jolliet et al. 2015). The product intake fraction (PiF) is analogous to the intake fraction (iF) (Bennett et al. 2002) used to relate environmental emissions to exposure in LCIA, but instead of intake per kilogram emitted (iF), PiF has units of chemical intake per kilogram of chemical initially in the product. In this way, exposure to chemicals in food packaging can be added to an LCIA characterization framework that typically only includes exposures to mass in the environment, where given the mass of a chemical in a package ($m_p$, $kg$), the PiF ($kg_{intake}$ $kg_p$), the assumption that 100% of the food item is ingested, and effect factors (*EFs, disease cases* $kg^{-1}$) impact (*I, disease cases*) was estimated as $I = m_p \times PiF \times EF$. To model PiF we adapted a widely used regulatory model (Begley et al. 2005) for migration of chemicals from food packaging into food and applied realistic (instead of worst-case) partition and diffusion coefficients. We then explored this model for one chemical for various food and plastic combinations.

## 3. Results

Only one chemical, styrene (CAS 100-42-5), was identified to occur in HIPS packaging and in life cycle inventory. With over >6,500 substances known to be used in food contact materials such as food packaging (Neltner et al. 2013; Oldring et al. 2014) only 18 chemicals total were identified to definitively occur in HIPS (although likely many more occur in reality, and the exact composition will vary from package to package). To our knowledge no publically available database matches chemicals with specific packaging types, but only to e.g. 'polymers' in general. Out of these chemicals only the styrene monomer had effect factors (EF) available in USEtox. Furthermore, out of the 17 other chemicals only 7 were readily able to be matched to a CAS number. No Observable Adverse Effect Levels (NOAELs) were only available for 3 chemicals with CAS numbers from toxicity studies (personal communication with RIVM) which were required to estimate EF for characterization (CAS numbers 61167-58-6, 7128-64-5, 36443-68-2).

Screening life cycle exposure to styrene alone (Figure 1), the material acquisition stage was a hot spot when exposure through packaging use (i.e. through consuming food) was not considered. However, when considered, exposure to styrene through packaged food consumption (due to consuming 1 kilogram of packaged yogurt) was greater than the exposure of the entire population due to life cycle emissions of styrene related to producing packaging for 1 kilogram of yogurt. When further extending this analysis (Figure 2) to include characterization of exposure to styrene as well as the three other chemicals known to migrate into food from HIPS packaging (where concentration in yogurt and other foods was *unknown*), we found a similar result, that even when considering consumer exposure to only four chemicals migrating from HIPS into 1kg of food, at *levels at or below regulatory safety thresholds,* the human toxicity potential exceeded aggregated exposure to these chemicals from the other packaging life cycle stages. Specifically, when ≥1% of the allowable amount to migrate from packaging into food was considered, exposure through 1kg packaged yogurt constituted more than 30% of the entire life cycle human toxicity potential when considering the chemicals included in this analysis. We did not consider food waste which would decrease exposure through consumption and increase environmental impacts relative to 1kg yogurt *consumed*.

When data were completely lacking for concentrations of chemicals in packaged food we explored preliminary migration modeling. Through modeling various food-package combinations we

corroborated previous findings that the type of food (and its fat content) as well as the type of package (and its diffusivity properties) drastically influenced results.

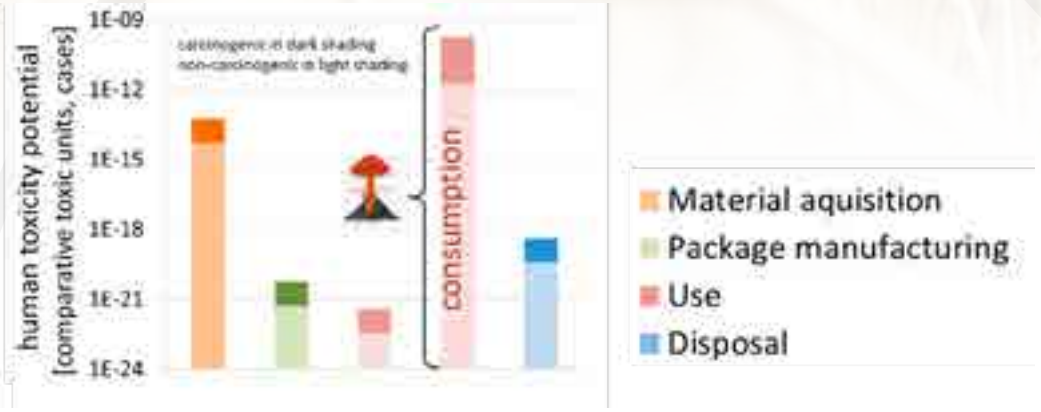


Figure 1: Human toxicity potential for life cycle exposure to styrene in food packaging (volcano is the symbol for the 'hotspot'.

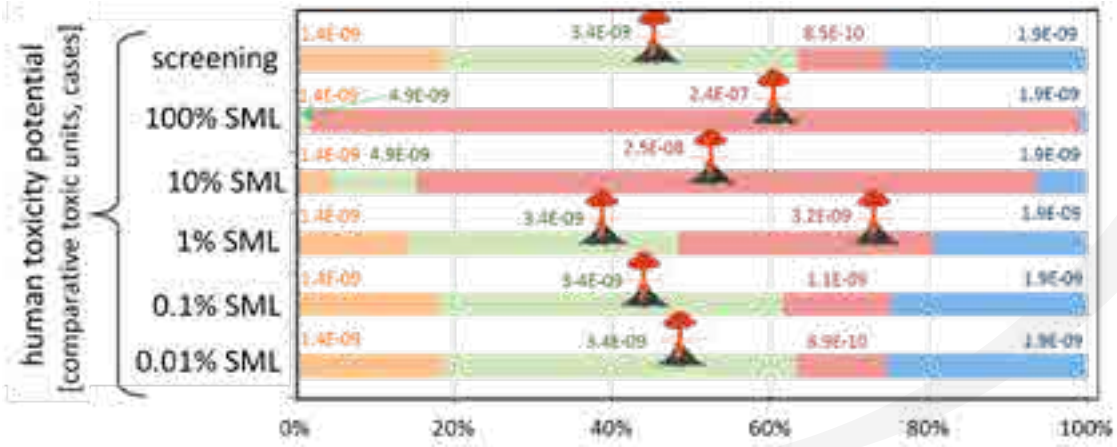


Figure 2 (same legend as Figure 1, with volcano symbols for hot spots): Use stage exposure via consuming packaged food to 5 chemicals was estimated and characterized as a function of the allowable amount to migrate from packaging into food according to regulatory specific migration limits (SML), where there is no SML established for styrene, so realistic exposure was used in all cases, but styrene contributed negligibly to use stage HTP via consumption of food.

## 4. Discussion

Consideration of exposure to chemicals in **food packaging** is currently missing from Cradle to Cradle and Ecolabel certification/licensing and Life Cycle Asssement (LCA), although chemical exposure via food packaging is a potential human health risk. In order to characterize chemicals in food packaging in LCIA, there are substantial obstacles. First, many chemicals occur in plastic as non-intentionally added substances (NIAS) which may not be assessed or known (Hoppe et al. 2016). Furthermore, even when substances are known to occur, data availability on chemical occurrence (e.g. frequency of occurrence, and type of packaging) in packaging is often protected by confidentiality agreements. These issues pose substantial barriers to developing an inventory of frequently occurring chemicals and their concentrations in packaging, however for a specific LCA study a practitioner may be able to gain knowledge from the assessment commissioner. Secondly, a main concern about chemicals in food packaging is the possibility of endocrine disruption as a mode of action for disease.

At this stage, it is unlikely regulatory animal tests at relatively high levels of exposure (e.g. mg/kg/day), which form the bases of both LCIA effect factors and allowable amounts in food specified by specific migration limits and other regulatory levels, cover low-level effects of endocrine disruption (which can result in carcinogenic effects and/or reproductive effects and/or other biological effects) and this contentious topic is under debate by regulators both in Europe and the United States (Muncke et al. 2014).

If the methods we develop are used in an LCA comparing virgin and recycled packaging materials, it is likely that recycled materials will demonstrate higher human toxicity potential through packaged food consumption (Biedermann and Grob 2013; Lee et al. 2014). With increasing effort towards developing a **circular economy**, especially for plastics, chemicals in materials that can be reused for food packaging is a central issue to ensuring the viability of material streams (World Economic Forum and Ellen MacArthur Foundation 2016). The methods developed in this study provide **first steps towards quantitative consideration of chemicals migrating into food from packaging in sustainability assessments**. However, it will be important that the interpretation of such possible results does not discourage recycling and resource use efficiency, but instead encourages systemic *improvement* of recycling systems for food packaging because of decreased impacts associated with recycled materials (Laurent et al. 2014). Furthermore, modeling demonstrated that the food-package combination is an important consideration. Because the food-package combination can lead to large variations in exposure to chemicals through packaging use, glass may be a more desirable package (leading to substantially less human toxicity potential through packaged food) for certain food products that have high potential for migration such as fatty foods and alcoholic beverages or products that are sterilized or pasteurized in bottles (i.e. fruit juices).

When empirical data are unavailable to estimate migration of known substances from a package into a food, modeling is a useful approach however it comes with substantial uncertainties tied to the required estimation of the diffusion coefficient and partition coefficient for the chemical from packaging into food (Begley et al. 2005). The model applied in this study is mostly used to estimate migration from packaging to liquid food items, and compiled data are not available to corroborate this model for a physicochemical space or across package-food combinations.

## 5. Conclusions

In this study we provide for the first time characterization of exposure to chemicals migrating from packaging into food in a life cycle context to test if this exposure pathway is important to consider in LCA. Data limitations (i.e., occurrence of chemicals in specific packaging types, their concentrations in packaging and/or packaged food, and effect factors) were a main obstacle to this exploration. Nevertheless, results demonstrate that even when characterizing only 4 chemicals migrating from packaging into food, at levels well below regulatory compliance, potential human toxicity due to food consumption was far greater than the potential human toxicity estimated for each considered life cycle stage following ILCD methodology. This implies that the use stage of food packaging (i.e. consuming the packaged food), at least for yogurt packed in HIPS, but likely for other packaging materials and food combinations, can be a human toxicity hot spot. Such a finding implies that exposure to chemicals in food packaging via food is the most important aspect to minimize potential toxicity throughout the life cycle. The results also imply that when designing eco-friendly food packaging exposure through use is an important consideration as a potential trade-off.

## 6. References

Amienyo, D., Gujba, H., Stichnothe, H., and Azapagic, A. 2012. Life cycle environmental impacts of carbonated soft drinks. Int. J. Life Cycle Assess. 18, 77–92.

Begley, T., Castle, L., Feigenbaum, A., Franz, R., Hinrichs, K., Lickly, T., Mercea, P., Milana, M., O'Brien, A., Rebre, S., et al. 2005. Evaluation of migration models that might be used in support of regulations for food-contact plastics. Food Addit. Contam. 22, 73–90.

Belboom, S., Renzoni, R., Verjans, B., Léonard, A., and Germain, A. 2011. A life cycle assessment of injectable drug primary packaging: comparing the traditional process in glass vials with the closed vial technology (polymer vials). Int. J. Life Cycle Assess. 16, 159–167.

Bennett, D.H., McKone, T.E., Evans, J.S., Nazaroff, W.W., Margni, M.D., Jolliet, O., and Smith, K.R. 2002. Peer Reviewed: Defining Intake Fraction. Env. Sci Technol 36, 206A–211A.

Biedermann, M., and Grob, K. 2013. Assurance of safety of recycled paperboard for food packaging through comprehensive analysis of potential migrants is unrealistic. J. Chromatogr. A 1293, 107–119.

Blum, A., Balan, S.A., Scheringer, M., Trier, X., Goldenman, G., Cousins, I.T., Diamond, M., Fletcher, T., Higgins, C., Lindeman, A.E., et al. 2015. The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFASs). Environ. Health Perspect. 123, A107–A111.

Dhaliwal, H., Browne, M., Flanagan, W., Laurin, L., and Hamilton, M. 2014. A life cycle assessment of packaging options for contrast media delivery: comparing polymer bottle vs. glass bottle. Int. J. Life Cycle Assess. 19, 1965–1973.

Flanigan, L., Frischknecht, R., and Montalbo, T. 2013. An analysis of life cycle assessment in packaging for food and beverage applications.

Gärtner, S., Balski, M., Koch, M., and Nehls, I. 2009. Analysis and Migration of Phthalates in Infant Food Packed in Recycled Paperboard. J. Agric. Food Chem. 57, 10675–10681.

Genualdi, S., Nyman, P., and Begley, T. 2014. Updated evaluation of the migration of styrene monomer and oligomers from polystyrene food contact materials to foods and food simulants. Food Addit. Contam. Part A 31, 723–733.

Gérand, Y., and Roux, P. 2014. Novinpak® system Life Cycle Assessment, Comparitive life cycle assessment of the Novinpak® PET bottle vs. traditional glass bottle including win manufacturing.

Geueke, B., Wagner, C.C., and Muncke, J. 2014. Food contact substances and chemicals of concern: a comparison of inventories. Food Addit. Contam. Part -Chem. Anal. Control Expo. Risk Assess. 31, 1438–1450.

Grönman, K., Soukka, R., Järvi-Kääriäinen, T., Katajajuuri, J.-M., Kuisma, M., Koivupuro, H.-K., Ollila, M., Pitkänen, M., Miettinen, O., Silvenius, F., et al. 2013. Framework for Sustainable Food Packaging Design. Packag. Technol. Sci. 26, 187–200.

Hoekstra, E.J., Brandsch, R., Dequatre, C., Mercea, P., Störmer, A., Trier, X., Vitrac, O., Schäfer, A., and Simoneau, C. 2015. Practical guidelines on the application of migration modelling for the estimation of specific migrationE.J. Hoekstra, R. Brandsch, C. Dequatre, P. Mercea, M.R. Milana, A. Störmer, X. Trier, O. Vitrac A. Schäfer and C. Simoneau; (European Commission, Joint Research Centre).

Hoppe, M., de Voogt, P., and Franz, R. 2016. Identification and quantification of oligomers as potential migrants in plastics food contact materials with a focus in polycondensates – A review. Trends Food Sci. Technol. 50, 118–130.

Huijbregts, M.A.J., Rombouts, L.J.A., Ragas, A.M.J., and van de Meent, D. 2005. Human-toxicological effect and damage factors of carcinogenic and noncarcinogenic chemicals for life cycle impact assessment. Integr. Environ. Assess. Manag. 1, 181–244.

Humbert, S., Rossi, V., Margni, M., Jolliet, O., and Loerincik, Y. 2009. Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots. Int. J. Life Cycle Assess. 14, 95–106.

Hunt, R.G., and Franklin, W.E. 1996. LCA — How it came about. Int. J. Life Cycle Assess. 1, 4–7.

Jolliet, O., Ernstoff, A.S., Csiszar, S.A., and Fantke, P. 2015. Defining Product Intake Fraction to Quantify and Compare Exposure to Consumer Products. Environ. Sci. Technol. 49, 8924–8931.

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M.Z., and Christensen, T.H. 2014. Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives. Waste Manag. 34, 573–588.

Lee, J., Pedersen, A.B., and Thomsen, M. 2014. The influence of resource strategies on childhood phthalate exposure—The role of REACH in a zero waste society. Environ. Int. 73, 312–322.

Muncke, J., Myers, J.P., Scheringer, M., and Porta, M. 2014. Food packaging and migration of food contact materials: will epidemiologists rise to the neotoxic challenge? J. Epidemiol. Community Health.

Neltner, T.G., Alger, H.M., Leonard, J.E., and Maffini, M.V. 2013. Data gaps in toxicity testing of chemicals allowed in food in the United States. Reprod. Toxicol. 42, 85–94.

Oldring, P.K.T., O'Mahony, C., Dixon, J., Vints, M., Mehegan, J., Dequatre, C., and Castle, L. 2014. Development of a new modelling tool (FACET) to assess exposure to chemical migrants from food packaging. Food Addit. Contam. Part Chem. Anal. Control Expo. Risk Assess. 31, 444–465.

Robertson, G.L. 2012. Food Packaging: Principles and Practice, Third Edition (CRC Press).

Serrano, S.E., Braun, J., Trasande, L., Dills, R., and Sathyanarayana, S. 2014. Phthalates and diet: a review of the food monitoring and epidemiology data. Environ. Health 13, 43.

Weidema, B.P., Bauer, C., Hischier, R., Mutel, C., Nemecek, T., Reinhard, J., Vadenbo, C.O., and Wernet, G. 2013. The ecoinvent database: Overview and methodology, Data quality guideline for the ecoinvent database version 3, www.ecoinvent.org.

World Economic Forum and Ellen MacArthur Foundation 2016. The New Plastics Economy: Rethinking the future of plastics.

Yuan, G., Peng, H., Huang, C., and Hu, J. 2015. Ubiquitous Occurrence of Fluorotelomer Alcohols in Eco-Friendly Paper-Made Food-Contact Materials and Their Implication for Human Exposure. Environ. Sci. Technol. 942–950.